High-Intensity Soil Survey and Hydropedologic Functional Map Units

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abstract

The fundamental purposes of a soil survey are to show (cartographically) the geographic distribution of the soils and make land-use predictions about those soils. A wide array of environmental, ecological, agricultural, geological, and natural resource issues have placed greater demands on soil survey information. Traditional soil maps, soil map units, and interpretations may be inadequate when confronting these complex issues, and in particular, issues that require detailed hydrologic information.

Two soil-landscape case studies are presented to evaluate the utility of traditional soil maps and high intensity soil maps in the mapping and interpretation of hydropedological properties. The concept of a Hydropedological Functional Unit (HFU) will be introduced as a means of cartographically representing critical and more detailed hydropedological functions related to soil–landscape relationships. HFUs are unique mappable areas at a particular scale of resolution, created through interaction of pedogenic features and hydrologic processes.

A forested catchment and a cultivated catchment were selected for the study. Two levels of soil survey (first and second order) were evaluated at each site for their cartographic representation of soil-landscape hydrology. We evaluated the hydropedologic utility of a soil survey by analysis of intensive soil property point data, detailed soil-landscape and geomorphic analysis, and geophysical techniques.

At both sites, the second-order soil survey captured soil variation, but had low spatial resolution and uniform attribute value (uniform spatial information as depicted within polygons) within map units delineated to have significantly different hydropedological utility. The first soil surveys showed higher spatial resolution, but were constrained by uniform attribute value within map units.

The results of these two case studies suggest that traditional soil survey and even high intensity soil survey may not be adequate to map and interpret a soil landscape's hydropedological function. Another level of cartographic data is needed to more accurately and precisely map the critical soil water processes that range from pedon scale to landscape and landform scale. This article introduces the concept of Hydropedologic Functional Map Units (HFU) as a cartographic building block to increase knowledge, understanding, and utility of soil–landscape hydrology for various applications.

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Study Objective

The study was conducted to evaluate the utility of both traditional and high intensity soil maps in the mapping and interpretation of soil-landscape hydropedological properties. The focus is on evaluating the ability of first- and second-order soil surveys to depict soil-landscape hydrological processes (e.g., interception, runoff, infiltration, percolation, storage, evaporation, and transpiration). After the initial evaluations the concept of the HFU as a cartographic building block will be introduced to determine if a HFU map unit, and in turn a HFU data layer, will increase knowledge, understanding, and utility of soil-landscape hydrology.

Traditional Soil Maps and their Interpretations

The fundamental purposes of a soil survey are to show (cartographically) the geographic distribution and make predictions about the soils (Soil Survey Staff, 1993). To this end, a soil survey includes soil maps, map unit descriptions, soil series descriptions, taxonomic classifications, and interpretations for the use and management of the soils.

Published soil surveys are typically second and third order in the United States, which range in scale from 1:12,000 to 1:31,680 and 1:20,000 to 63,360, respectively (Soil Survey Staff, 1993). These surveys commonly have 10 to 15 tables that include interpretations for plants, urban land use, rural development, recreational development, and for conservation and wildlife habitat planting (Soil Survey Staff, 1993). The soil survey interpretation tables are based on soil properties, qualities, and behaviors gathered at traditional soil survey scales of observation (i.e., second and third orders).

A wide array of environmental, ecological, agricultural, geological, and natural resource issues have placed greater demands for more accurate, precise, and problem-specific soil survey information. A few of these challenges are nutrient management, sewage disposal, water resource plans, storm water management, and wetland protection (Lin et al., 2006a). Many of these challenges also require detailed hydrologic information. Traditional soil maps and their interpretations may be inadequate when confronting these complex issues (Indorante et al., 1996; Lin 2003; Zhu et al., 1997; Lin et al., 2006a,b).

Two major limitations of soil information derived from conventional second- and third-order soil maps are (i) low spatial resolution and (ii) uniform attribute value within the unit delineated (e.g., all spatial information is depicted as the same within the boundaries of the soil polygons) (Zhu et al., 1997). High-intensity soil survey (first-order surveys completed at scales larger than 1:15,840) can be applied to specific study sites to address these limitations, but the problem of uniform attribute value still remains. Another limitation is that minimal temporal hydrologic information is included at all three levels of soil surveys (Lin et al., 2006c).

Hydropedology

To address the above issues and soil survey limitations, Lin (2003) suggested bridging traditional pedology (i.e., soil survey) with soil physics and hydrology and integrating studies of soil–water relationships across both spatial and temporal scales. The bridge that is suggested is *hydropedology.* Lin (2003) defines hydropedology as an intertwined branch of soil science and hydrology that encompasses multiscale, basic, and applied research of interactive soil and water processes and their properties in the unsaturated zone.

Hydropedology integrates pedology and hydrology to study soil–water interactions and landscape–soil–hydrology relationships across spatial and temporal scales, aiming to understand pedologic controls on hydrologic processes and properties, and hydrologic impacts on soil formation, variability, and functions (Lin et al., 2006c). Hydropedology emphasizes in situ soils on landscapes where distinct pedogenic features (such as soil structure, layering, and heterogeneity), environmental variables (such as climate, landform, and organism), and anthropogenic impacts (such as land use and management) prevail and interact.

To incorporate hydropedologic concepts into detailed and high-intensity soil surveys a cartographic unit that includes hydrologic processes is needed. To fill this need, the concept of a HFU is introduced as a means of cartographically representing critical and more detailed hydropedologic soil-landscape functions (Lin et al., 2006c).

Working Definition of the Hydropedologic Functional Unit

The HFU is a unique mappable area, at a particular scale of resolution, created through the interaction of pedogenic features and hydrologic processes.

Pedogenic features encompass the five soil forming factors, which all have an impact to one degree or another on soil properties and hydrology, and include soil properties. Pedogenic features are mappable at multiple scales (e.g., from pedon description level to soil map level), but the primary level of detail for the HFU is the landscape and landform level. Hydrologic processes include interception, runoff, infiltration, percolation (recharge, flowthrough, and discharge), storage, evaporation, and transpiration.

The goal of the HFU is to subdivide the landscape into similarly functioning hydrologic units (map units) by grouping areas that have similar storage, flux, pathway, and residence time of water in the soil landscape (Lin et al., 2006b,c). These units can be identified and delineated using traditional soil survey methods and data (e.g., soil maps and interpretations) in conjunction with new techniques (e.g., geophysical, remote sensing, field instrumentation), and data sources (e.g., digital elevation models, GIS).

Material and Methods

The Case Studies

Two soil-landscape case studies are presented to evaluate the utility of traditional (second order) and high intensity (first order) soil maps in delineating HFUs. Study areas are the Shale Hills Site in central Pennsylvania (Lin et al., 2006a) and the Morgan Pond Site in southern Illinois (Wilson et al., 2009). The Shale Hills Site is located in the Northern Appalachian Ridges and Valleys Major Land Resource Area (MLRA) (USDA-NRCS, 2006). It is a forested, first-order watershed approximately 7.8 ha in size. It is characterized by steep slopes (25– 35%) and narrow ridges. Within this catchment, soils were formed in colluvium or residuum weathered from shale. The Morgan Pond Site is located in the Central Mississippi Valley Wooded Slopes, Western Part MLRA. The Morgan Pond Site is a cultivated, first-order watershed approximately 10 ha in size. This catchment is characterized by slopes ranging from 0 to 5% on the ridges and 5 to 18% on the side slopes. Within this catchment, soils were formed in loess. Loess thickness on the summit was measured at 4.5 m.

The second-order soil survey information (Soil Survey Geographic [SSURGO] Database) was obtained for each site from Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/ [verified 17 Sept. 2009]). A first-order soil survey was completed at each site. Survey protocol varied with each site. An intensive grid method with transects was used to conduct the first-order soil survey for the Shale Hills Site (Soil Survey Staff, 1993; Lin et al., 2006a). For the Morgan Pond Site, soil-landscape units were first delineated and then intensive point data were collected within each soil-landscape unit (Wilson et al., 2009) to develop the first-order survey. At each site, an evaluation of the soil surveys hydropedologic utility was made by analysis of intensive soil property point data, detailed soil-landscape and geomorphic analysis, and electromagnetic induction (EMI) techniques (specifically the EM38 meter). Both site surveys were completed with the EM38 meter operated in the vertical dipole orientation. When placed on the surface the EM38 meter provides a nominal penetration depth of 1.5 m.

Results and Discussion

Evaluation of Second- and First-Order Soil Surveys

The second-order surveys (Table 1, Fig. 1 and 2) at both sites meet the needs of traditional soil surveys. Each survey had segmented the landscape into soil map units, and the map units were described and interpreted for common land use concerns (Soil Survey Staff, 1993). The first-order surveys (Table 1, Fig. 1 and 2) at both sites show greater detail, as displayed by the greater number of soil map units at each site. The high-intensity soil map of the Morgan Pond Site shows greater detail than the Shale Hills map, primarily due to the perceived land uses and the greater number of slope and erosion phases that are recognized in cultivated areas.

Even though there is greater detail in the first-order soil surveys, the data (Table 1, Fig. 1 and 2) and associated interpretations are still based on information developed at the second-order level. Also, with greater detail there are still concerns of low spatial resolution and uniform attribute value within the unit delineated. The first-order survey data also lacks spatial and temporal hydrology information. In summary, spatial and temporal variations in hydropedological properties are not fully understood nor incorporated into existing soil survey models.

Table 1. Second- and first-order soil survey information.

Map unit label†	Soil series	Parent material	Geomorphic component‡	Slope profile§	Slope range	Depth to bedrock
					%	m
Second-order soil survey:						
Morgan Pond Site (Cultivated), Union County, IL						
79	Menfro	Loess	IF, SS, NS	SU, SH, BS	2–18	>2.0
8333	Belknap (Ocassionally Flooded)	Alluvium	AF	FS, TS	0–2	>2.0
Shale Hills Site (Forested), Huntingdon County, PA						
BID	Berks-Weikert	Shale	IF, HS, SS	SU, SH, BS	10–25	<0.5
BmF	Berks-Weikert	Shale	IF, HS, SS	SU, SH, BS	steep	<0.5
BkC	Berks	Shale	IF, HS, SS	SH, BS	8–15	0.5–1
	Rushtown	Colluvium	IF, HS, SS	SH, BS	3–52	>1.0
	Blairton	Shale	HS	FS	0–35	>1.0
ErB	Ernest	Colluvium	CF	FS	3–18	>1.0
First-order soil survey:						
Morgan Pond Site (Cultivated), Union County, IL						
79	Menfro	Loess	IF, SS, NS	SU, SH, BS	2–18	>2.0
621	Bunkum	Loess	SS, HS	BS,FS	2–10	>2.0
214	Hosmer	Loess	IF, SS, HS	SU, SH, BS	2–18	>2.0
336	Wilbur	Alluvium	AF	FS, TS	0–2	>2.0
Shale Hills Site (Forested), Huntingdon County, PA						
Weikert	Weikert	Shale	IF, HS, SS	SU, SH, BS	0–52	<0.5
Berks	Berks	Shale	IF, HS, SS	SH, BS	0–52	0.5–1
Rushtown	Rushtown	Colluvium	IF, HS, SS	SH, BS	3–52	>1.0
Blairton	Blairton	Shale	HS	FS	0–35	>1.0
Ernest	Ernest	Colluvium	CF	FS	0–50	>1.0

† For Illinois' slope classes are designated as A, 0–2%; B, 2–5%; C, 5–10%; D, 10–18%. The number after the slope designation is erosion class. No number, none to slight; 2, moderate; and 3, severe.
‡ IF, interfluve; HS, headslope; SS, sideslope; CF, colluvial fan; AF, alluvial fill.
§ SU, summit; SH, shoulder; BS, backslope; FS, footslope; TS, toeslope.

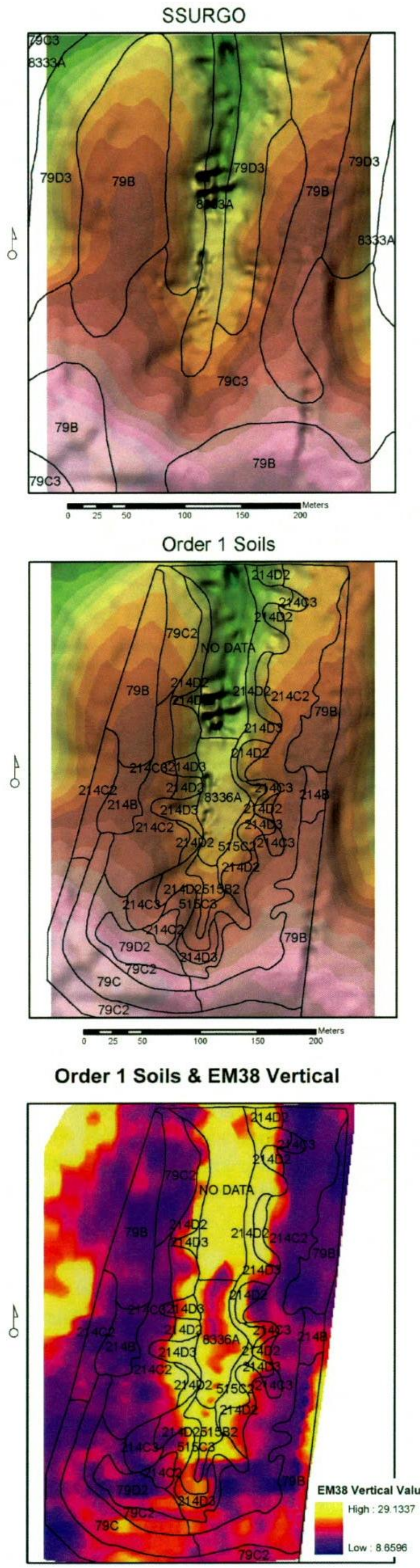

Fig. 1. (right) Second- and first-order soil maps and map of EM38 values (mS/m) for the Morgan Pond Site. Boundaries on the edge of the first-order survey delineate the edge of the study area rather than mapping unit boundaries.

Building on the Second- and First-Order Soil Surveys

The data collected in second and first-order surveys need to be built upon using different and evolving technologies to supply critical spatial and temporal hydropedological information. One such technology is EMI. This technique is used extensively in precision agriculture as well as for mapping of soil parameters (Jaynes, 1996; Vitharana et al., 2008). The EMI measures apparent conductivity (EC_a, with the unit of measure for this study being mS/m), which is dependent on the water, clay, and soluble salt contents of soils. EC_a patterns are established that reflect ephemeral differences in moisture content for soils that have low soluble salts and relatively stable clay content and distribution (e.g., the soils in this study). Therefore, the EC patterns, in essence, could be the basis for defining the unit areas of the HFU. The HFU developed from EC_a remain relatively static and similar in pattern regardless of soil moisture contents as the ECa increases proportionally with soil moisture regardless of the landscape area. In other words, general spatial EC_a patterns remain relatively similar in location and extent, regardless of moisture content.

The soils and landscapes of both sites are highly suited for investigation and interpretation with EMI. The EMI surveys at each site (Fig. 1 and 2) suggest differences in EC_a associated with hydropedological properties and different landscape components within these two small catchments. The EMI survey also show spatial differences between the EC_a and the first-order soil survey. At the Shale Hills Site there is significant variation in EC_a readings within the first-order soil map units. At the Morgan Pond Site there is a better correspondence between

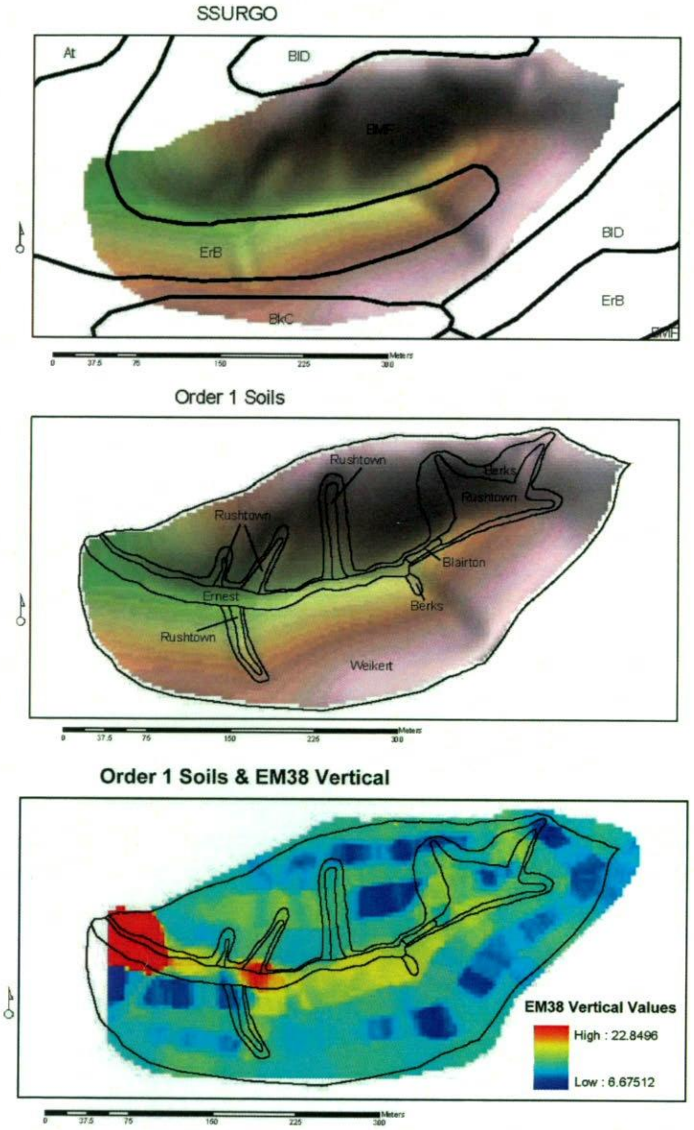

Fig. 2. Second- and first-order soil maps and map of EM38 values (mS/m) for the Shale Hills Site.

the EC_a and the first-order soil lines, but there are many instances of similar EC_a readings occurring across the soil boundaries. Even though the high-intensity soil surveys at both sites showed higher spatial resolution, the EMI data suggest that the maps were still constrained by uniform attribute value within map units and limited temporal information. These observations suggest that there is potential to display the hydropedological functions of the soil landscape more precisely, accurately, and cartographically using HFUs as a map unit and as an additional data layer used in conjunction with first-order soil survey information.

Conclusions

The initial results of these two case studies suggest that traditional second-order soil surveys and even first-order soil surveys may not be adequate to map and interpret a soil landscape's hydropedological function. Much work is still needed in defining and applying the concept of the HFU to help in the understanding and mapping of a soil landscape's hydropedological function. Nevertheless, the concept of HFU is appealing as a cartographic building block to increase knowledge transfer and utility of soil-landscape hydrology information. The development of the HFU concept, along with in situ hydrologic data collections over time, can become an integral part of modern high intensity soil survey and natural resource spatial databases that can serve diverse practical applications.

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